When *Some* is Not *Every*: Dissociating Scalar Implicature Generation and Mismatch

Einat Shetreet,[1,2]* Gennaro Chierchia,[2] and Nadine Gaab[1,3,4]

[1]*Laboratories of Cognitive Neuroscience, Division of Developmental Medicine, Department of Medicine, Children's Hospital Boston, Boston, Massachusetts*
[2]*Department of Linguistics, Harvard University, Cambridge, Massachusetts*
[3]*Harvard Medical School, Boston, Massachusetts*
[4]*Harvard Graduate School of Education, Cambridge, Massachusetts*

Abstract: Making inferences beyond the literal meaning of sentences occurs with certain scalar expressions via scalar implicatures. For example, adults usually interpret *some* as *some but not all*. On the basis of behavioral research, it has been suggested that processing implicatures is cognitively costly. However, many studies have used cases where sentences with *some* did not match the context in which they were presented. Our study aimed to examine whether the processing cost is linked to implicature generation, to the mismatch between the implicature and the context, or to both processes. To do so, we explored the neural patterns of implicature generation and implicature mismatch using fMRI. Thirteen participants performed a sentence-picture matching task (where pictures determined the context) with mismatched implicatures, successful implicatures or no implicature conditions. Several brain regions were identified when comparing cases of implicature mismatch and cases without implicatures. One of these regions, left-IFG, was jointly activated for mismatched and successful implicatures, as observed in a conjunction analysis. By contrast, left-MFG and medial-frontal-gyrus, were identified when comparing cases of implicature mismatch with cases of successful implicatures. Thus, the left IFG can be interpreted as being linked to implicature generation, whereas the other two areas seem to participate in the processing of the mismatch between the implicature and its context. Our results indicate that scalar implicatures induce processing cost in different ways. This should be considered in future research. *Hum Brain Mapp 35:1503–1514, 2014.*

Key words: semantics; pragmatics; quantifiers; fMRI; neurolinguistics; BA47

INTRODUCTION

In language comprehension, listeners often make inferences beyond the literal and logical meaning of the utterances that they hear. Enrichment of sentence meaning occurs through semantic and pragmatic processes and is part of everyday speech such as indirect requests, idioms, or metaphors. Of a special interest in current linguistics and psycholinguistics is the case of scalar expressions, such as *some*, that receive their enriched meaning via scalar implicatures [e.g., Guasti et al., 2005; Hendriks et al., 2009; Huang and Snedeker, 2009a,b; Noveck, 2001; Noveck and Posada, 2003; Papafragou and Musolino, 2003; Pouscoulous et al., 2007].

Contract grant sponsors: Mind/Brain/Behavior Initiative at Harvard University; The International Brain Research Organization, Children's Hospital Boston;

*Correspondence to: Einat Shetreet, Laboratories of Cognitive Neuroscience, Children's Hospital Boston, 1 Autumn St, Boston, MA, 02115. E-mail: einat.shetreet@childrens.harvard.edu

Received for publication 15 May 2012; Revised 7 January 2013; Accepted 8 January 2013
DOI: 10.1002/hbm.22269
Published online 9 April 2013 in Wiley Online Library (wileyonlinelibrary.com).

In the traditional linguistic approach [e.g., Grice, 1975; Horn, 1972, 1989; Levinson, 2000], it has been argued that *some* has a single lexical meaning that defines a lower boundary to express any quantity greater than none, including the maximum (i.e., some and possibly all). Typically, however, the meaning of *some* is enriched, via an inference called scalar implicature, to exclude the total set (i.e., some but not all). Consider the sentence *John ate some of the cookies*. A listener is likely to infer that John ate some but not all of the cookies. However, in other contexts where the speaker is not knowledgeable or in linguistically downward entailing contexts[1], *some* does not exclude *all*. For example, under the statement *if John eats some of the cookies, he'll get fat*, the listener infers that eating all of the cookies will make John fat as well.

Neogricean approaches assume that scalar implicatures originate in a scale that weak quantifiers, such as *some*, form with other quantifiers, such as *most* and *every* (other scales are "or" and "and", numbers or even adjectives like "warm" and "hot"; Gazdar, 1979; Grice, 1975; Horn, 1972; Levinson, 2000). The fact that the speaker of a sentence, who is assumed to be cooperative and well-informed, decided to use the expression *some*, rather than the stronger members of the scale (i.e., *all* or *every*), indicates to the listener that the same statement with the stronger members does not hold. While there is little doubt that implicatures are generated (through a consideration of scalar alternatives), there is disagreement as to whether this involves semantic operations [e.g., exhaustification, Chierchia et al., 2008] or pragmatic mechanisms [e.g., some aspect of theory of mind, Flobbe et al., 2008; Pijnacker et al., 2009]. Our findings are relevant to such debates [for further discussion, see for example Chierchia, 2004; Noveck and Sperber, 2007].

Evidence for the generation of scalar implicatures during sentence comprehension comes from different studies in adults using various methods. In eye movement studies, Huang and Snedeker [2009a,b] observed delays in look shifts to targets for sentences containing *some* compared with sentences containing *all* or numbers. Participants were presented with four characters and were asked, for example, to point to "the girl that has some of the socks". The two critical characters (girls in this case) had either the subset of that item (2/3 of the socks) or the whole set of a phonological distractor (3/3 of the soccer balls). For the *some* sentences, this temporary ambiguity was resolved by adults before reaching the disambiguating phrase. This indicates that a scalar implicature was derived. However, compared with sentences with *all* and numbers, looks to the target were delayed. Huang and Snedeker therefore argued that late pragmatic processes are involved in the generation of scalar implicatures. Evidence for late generation of scalar implicatures was also observed in a self-paced reading task [Breheny et al., 2006][2].

Several studies assessed implicature generation using cases in which weak scalar expressions were presented in contexts where the total set held, thus creating a mismatch between the sentences and the context [Guasti et al., 2005; Hendriks et al., 2007; Noveck, 2001; Noveck and Posada, 2003; Papafragou and Musolino, 2003; Pouscoulous et al., 2007]. For example, in a seminal behavioral study by Noveck [2001], underinformative statements (in French), such as "some giraffes have long necks", were used. These statements are logically true, but pragmatically incorrect (because we know that **every** giraffe has a long neck). This is a case of implicature mismatch, as the natural interpretation of the sentence does not match the context (i.e., our world knowledge about giraffes). In true/false judgment tasks, most adults give pragmatic responses and reject the underinformative statements [e.g., Papafragou and Musolino, 2003], although several studies have also observed some logical responses in adults [e.g., Feeney et al., 2004; Guasti et al., 2005; Noveck, 2001; Noveck and Posada, 2003; Smith, 1980]. Importantly, on-line studies showed that cases of mismatched implicatures had longer reaction times and produce less accurate responses compared with cases of successful implicatures (i.e., statements with weak scalar expressions presented with a context in which the total set does not hold. e.g., "some people have long hair") [Bott and Noveck, 2004].

It is often suggested in the psycholinguistic literature that the generation of scalar implicatures involves processing costs [e.g., Guasti et al., 2005; Noveck, 2001; Pouscoulus and Noveck, 2009]. That is, the generation of implicatures requires more cognitive resources compared to simple sentences (without implicatures). This is based on results from on-line studies [Bott and Noveck, 2004; Breheny et al., 2006; Huang and Snedeker, 2009a,b], as well as on findings from developmental studies. Studies with children show that they accept statements with weak scalar expressions in contexts where the total set holds as true [e.g., Guasti et al., 2005; Noveck, 2001; Smith, 1980]. Interestingly, studies have shown that when the informativeness of a statement is salient in the context, children respond more like adults [Guasti et al., 2005; Papafragou and Musolino, 2003; Papafragou and Tantalou, 2004; Verbuk, 2006]. Thus, researchers claim that children have the semantic/pragmatic capacity to derive the implicatures, but fail to do so due to their limited cognitive resources which are needed in order to derive scalar implicatures [e.g., Guasti et al., 2005; Noveck, 2001; Pouscoulus and

[1]Linguistically, a context is downward entailing iff it licenses 'subset inferences'. For example, negation licenses the inference from "*John doesn't like pizza*" to "*John doesn't like pizza with anchovies*", where the set of anchovie-pizza eaters is a subset of the pizza eaters. Besides negation, downward entailing contexts include the complement of verbs like *doubt* and the antecedent of conditionals (see, e.g., Chierchia, 2004).

[2]Note however that there is no direct evidence in Breheny et al. that the implicatures were indeed derived. They assumed the generation of the implicatures based on the delayed reaction times and the structure of the sentences used in their experiment.

Noveck, 2009]. Adults, on the other hand, have sufficient cognitive resources required to generate scalar implicatures. Thus, adults are able to derive the enriched meaning and give the pragmatic response, despite the increased processing costs.

However, one may argue that the processing cost, which is reflected in children's behavior with scalar implicatures (although not explicitly shown in adults' behavior), may originate from the mismatch between the derived implicature and the context, and not from the implicature generation per se. Implicature mismatch may induce a processing cost, beyond and in addition to the generation of the implicature itself. This additional cost may result from the fact that two meanings (the logical one and the enriched one) are activated, or simply because it is harder to evaluate the truth value of the statement when two separate pieces of meaning are involved. As most developmental studies examining scalar implicatures used cases of implicature mismatch, it is unclear if the processing cost originates in the implicature generation alone, the implicature mismatch alone or both together.

The present study is aimed to tease apart and isolate these processes in an adult sample, in an attempt to provide a first insight into the source of the processing cost related to scalar implicatures. Using fMRI, we examined the patterns of cortical activation associated with scalar implicatures in a mismatch context, as well as the activations associated with successful scalar implicatures. Various conjunction analyses of these conditions allowed us to distinguish processes of implicature generation from processes of implicature mismatch.

METHODS

Participants

Thirteen adult right-handed native English speakers without neurological, hearing or language impairment participated in the study (8 females, ages: 19–30, mean: 23.4). All participants gave informed consent prior to the experiment and were compensated for their participation. Two additional participants were excluded from the experiment: one due to technical problems and the other due to awareness to the experimental goal (the participant had extensive knowledge of linguistic theory). The study was approved by the Internal Review Board of Children's Hospital Boston.

Materials and Procedure

All the sentences used in this study included a quantifier (*some* or *every*) with a noun at the subject position. All the words in the sentences had age of acquisition prior to 5 years (as determined by the McArthur-Bates communicative development inventories, Dale and Fenson, 1996). The words were balanced across conditions, by using the same words in different combinations (e.g., "some elephants are drinking" with "every elephant is dancing" and "every giraffe is drinking"). Sentences were presented auditorily. A female native American English speaker recorded the sentences in random across conditions. Recording was performed using GoldWave software. There were no differences in the duration of the sentence among the conditions ($F(5, 119) = .696$, $p = .63$). Sentences described an action performed by the subjects (e.g., "every elephant is dancing"), the location of the subjects (e.g., "some zebras are on the boat"), or a possession of the subjects (e.g., "some giraffes have balloons").

Pictures were used to determine the context for the sentences. All the pictures included five individuals of the same type (e.g., five giraffes or five girls). There were three types of pictures: in one third, all the individuals had the same property that was stated in the sentence (e.g., five mice with grapes; Fig. 1A); in another third, three of the individuals had the same property (e.g., three skating lions; Fig. 1B); and the rest of the pictures had none of the characters with the property (e.g., no monkey on a couch; Fig. 1C).

The combination of sentence type (including *some* or *every*) with the picture type (ALL, SOME, or NONE) produced six conditions (Table I and Fig. 1): (1) *some*ALL—*some* sentences with ALL pictures. This is the condition of implicature mismatch and it includes processes of both implicature generation and implicature mismatch; (2) *some*SOME—*some* sentences with SOME pictures. This condition includes only implicature generation processes, as no mismatch was presented; (3) *some*NONE—*some* sentences with NONE pictures. It is not clear if this condition involves implicature generation, as the truth value of the sentence (i.e., "false") can be successfully determined on either the logical or the pragmatic construal; (4) *every*ALL—*every* sentences with ALL pictures; (5) *every*SOME—*every* sentences with SOME pictures; and (6) *every*NONE—*every* sentences with NONE pictures. Conditions (4–6) do not include any implicature-related processes, as they involve a strong quantifier, which never generates implicatures in positive contexts. Four additional conditions were included (with numbers instead of quantifiers). These will be discussed elsewhere (Shetreet et al., in preparation).

A simple sentence-picture matching task was used in the MRI scanner with an event related design: participants heard a sentence and saw a picture and were asked to decide if the sentence matches the picture. Each picture was presented for 4 s. The sentence was played with the initial display of the picture, and a response was required after the sentence has ended. Rest trials with fixation cross were also included and displayed for 4 s. Each condition appeared 20 times (with a total of 120 sentences) in two separate runs (10 sentences in each run). Each run lasted ~7.5 min. Trial randomization was determined by optseq (http://www.freesurfer.net/optseq). Stimuli were delivered to the participants using Presentation software (http://nbs.neuro-bs.com). All the responses and reaction times were recorded.

Prior to the MRI scan, participants watched an instruction video and practiced the task with sentences and

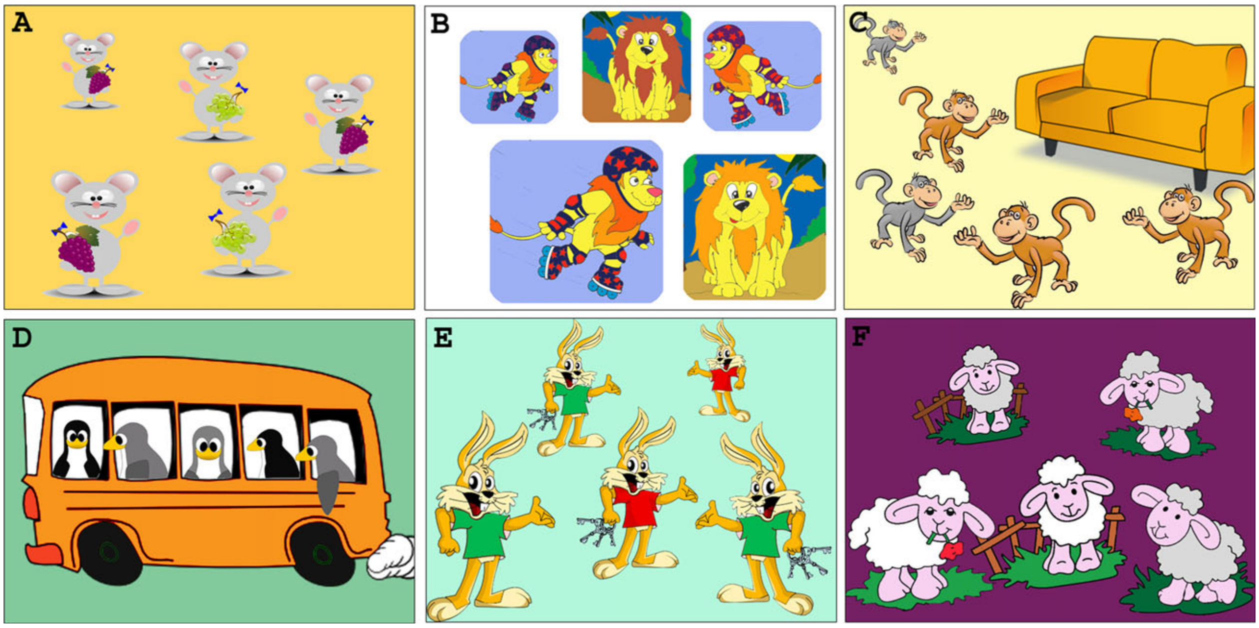

Figure 1.

Examples of pictures used in the experiment. Picture (**A**) was presented with the sentence "some mice have grapes" (for the mismatch condition), Picture (**B**) with "some lions are skating", Picture (**C**) with "some monkeys are on the couch", Picture (**D**) with "every penguin is on the bus", Picture (**E**) with "every rabbit has keys", and Picture (**F**) with "every sheep is drinking". [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

pictures that were not used in the experimental task itself. No mismatch scenarios were included in the practice. Participants did not show any difficulties with this task, and feedback about their performance was given to them after the practice. Participants performed other tasks inside and outside of the MRI. The entire MRI session, including anatomical scans, lasted approximately an hour.

Data Acquisition

MRI scans were conducted in a whole-body 3 Tesla, SIEMENS 3T Trio MR scanner. Functional MRI was performed using a gradient-echo T2*-weighted EPI interleaved sequence with 227 whole-brain images in each run. Thirty-two sagital slices 4 mm thick, covering the whole of the cerebrum and most of the cerebellum, were selected. Our acquisition parameters were: FOV = 192, matrix size = 64x64, TR = 2000ms, TE = 30ms, and flip angle = 90°.

Data Analysis

Image analysis was performed using SPM8 (Wellcome Department of Cognitive Neurology, http://www.fil.ion.ucl.ac.uk/spm/). Functional images from each subject were slice-time corrected for interleave acquisition, motion-corrected, normalized to the SPM EPI template, and spatially smoothed using a Gaussian filter (4-mm kernel). Each subject's data was analyzed using a general linear model [GLM, Friston et al., 1995] and high-pass filtered at 128s. Events were modeled with the onset of the sentence/picture (which was the same) and with the duration of the entire trial (to capture processes of implicature generation

TABLE I. The conditions used in the experiment

Condition	Scalar expression	Picture	Expected response	Scalar implicature
*some*ALL (implicature mismatch)	some	ALL	match (logical) / no-match (pragmatic)	yes
*some*SOME (successful implicature)	some	SOME	match	yes
*some*NONE	some	NONE	no-match	unknown
*every*ALL	every	ALL	match	no
*every*SOME	every	SOME	no-match	no
*every*NONE	every	NONE	no-match	no

as well as decision making, which is relevant to the mismatch processing). As subjects differed with regard to their responses on the *some*ALL condition (see Results), we added a covariate with the responses for this condition. Head motion parameters were added as regressors [Friston et al., 1995].

For the group-level analyses, one-sample *t*-tests were computed using the individual contrast images. Most of the reported analyses were done using an inclusive conjunction. This analysis uses a series of contrasts that define differences between conditions. Although such contrasts include various cognitive processes (e.g., the *some*ALL, but not the *some*SOME, condition include implicature mismatch), the conjunction analysis aims to reveal the commonalities between the contrasts (e.g., both the *some*ALL and the *some*SOME conditions include implicature generation). Activations identified by such analysis are thus assumed to be associated with a shared cognitive process. This analysis requires less a-priori assumptions regarding the differences between the cognitive processes included in the conditions, and it relies on the joint statistics of the individual contrasts [e.g., Price and Friston, 1997].

Using conjunction analyses, we were able to isolate activations linked to the tested processes, and screen out the ones related to specific differences between the conditions (e.g., response type or picture type etc). Analyses were carried out with the threshold of $P < 0.005$, cluster size of $k > 50$ voxels, and cluster-level FWE correction of $P < 0.05$. To localize the areas of activation, and identify the related Brodmann areas (BA), we used xjView (http://people.hnl.bcm.tmc.edu/cuixu/xjView/).

We further performed an ROI analysis in the areas observed in our baseline conjunction (obtained by comparing *some*ALL with the *every* conditions separately). Average beta values of all the conditions were extracted from these areas using MarsBar and planned comparisons were performed to compare the *some*SOME and *some*NONE conditions to the *every* conditions. The aim of this analysis was to assess the activations in response to the *some*SOME and *some*NONE conditions in those regions in which the *some*ALL condition showed increased activations (compared with the *every* conditions). This ROI analysis is not completely independent because the *every* conditions were used to define the ROIs initially, as well as in the planned comparisons with the someSOME and the someNONE conditions. However, an introduced ROI bias should influence both conditions to the same degree. Thus, any difference between these two comparisons cannot be explained by the nonindependence of the ROI.

RESULTS

Behavioral Measurement

Accuracy rates on all the conditions except the *some*ALL condition (for which both "yes" and "no" responses were acceptable) were above 80% (mean accuracy = 94.5%, SD = 4.3). For the *some*ALL condition, which has two possible interpretations, eight of the participants responded more with no-match for the sentence and the picture (pragmatic responders) whereas five gave more match responses (logical responders). Notably, three of the five logical responders commented on the *some*ALL condition after the experiment ended, indicating that both the logical and the pragmatic interpretations were available to them.

We tested the reaction times for all conditions using within-subject ANOVA for sentence type, using the responder type as a between-subject factor. This revealed no significant main effects ($F(2,10) = 0.5$, $P = 0.61$ for the responder type effect; $F(10,2) = 5.05$, $P = 0.17$ for the condition effect) or interaction ($F(10,2) = 1.44$, $P = 0.47$).

fMRI Results

We analyzed the data from both logical and pragmatic responders together. This was done based on several considerations. First, there was indication that the logical responders drew the implicature (based on their post-experimental reports[3]). Additionally, no difference in reaction times was found between the two responder types. Furthermore, the fMRI results of the pair comparisons at the individual subject level showed similar patterns of brain activation to the one observed at the group level. Finally, no difference in brain activation between a group of logical responders and a group of pragmatic responders was found in an ERP study [Noveck and Posada, 2003].

The first step of our analysis ("the baseline conjunction") was aimed to examine whether there are brain areas that demonstrate a processing cost with the critical condition, the implicature mismatch condition (*some*ALL). The next steps were aimed to uncover the roles of the areas identified in the baseline conjunction in the processing of implicatures. We examined the effects of the lexical meaning of *some*, as well as explored the areas that participate in the processing of implicature generation and those that participate in the processing of implicature mismatch.

Our baseline conjunction, which was designed to show the processing cost related to our critical condition, compared the *some*ALL condition to the *every* conditions. This conjunction was expected to reveal activations related to both implicature generation and implicature mismatch. It should show regions that participate in the implicature generation, the natural hypothesis being that the *some*ALL condition includes implicature generation, but none of the *every* conditions does. Additionally, it was expected to reveal regions involved in the processing of the implicature mismatch, in the case that this mismatch induces

[3]For example, one participant stated that there were instances where the sentence could be both a match and a no-match to the picture using an example from the *some*ALL condition. She further stated that in those instances she always gave a "yes" response, though she could not really make up her mind.

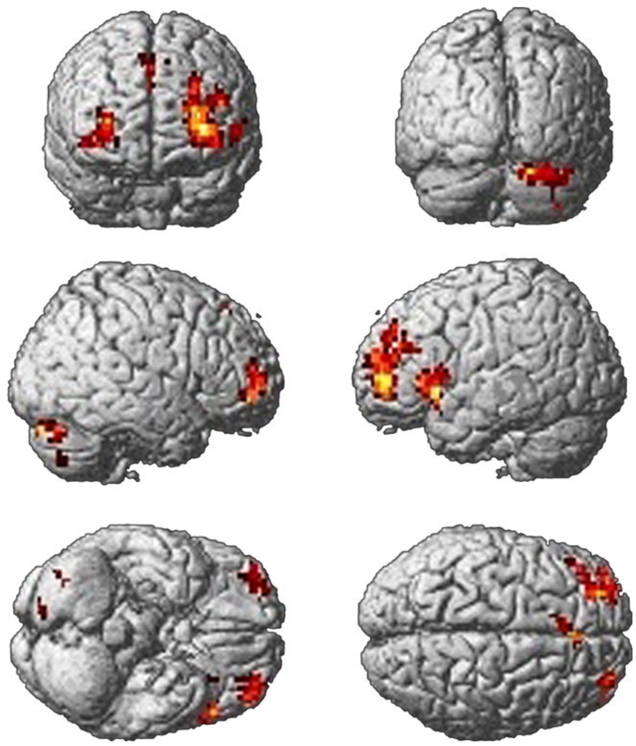

Figure 2.
Areas activated in the conjunction analysis of *some*ALL > *every*ALL, *some*ALL > *every*SOME and *some*ALL > *every*NONE, including the left IFG (BA 47), left and right anterior MFG (BA 10), MeFG/ACC, and the right cerebellum. Of these, the left IFG was also found in the conjunction analysis of *some*ALL > *every*ALL and *some*SOME > *every*ALL, whereas the left anterior MFG and the MeFG/ACC were found in the conjunction of *some*ALL > *some*SOME and *some*ALL > *some*NONE. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

processing cost. This is because only the *some*ALL condition (but not the *every* conditions) included such a mismatch[4]. Another difference that may also be revealed in this comparison concerns the lexical meaning of the quantifier (because the conditions used in this conjunction differed on the quantifier, i.e., *some* vs. *every*).

The results of the baseline conjunction analysis of the individual comparisons of *some*ALL and the *every* conditions (*some*ALL > *every*ALL, *some*ALL > *every*SOME, and *some*ALL > *every*NONE) showed bilateral activations in the anterior middle/superior frontal gyrus (mostly in Broadmann area (BA) 10), as well as activations in the left inferior frontal gyrus (IFG) (BA 47), the medial frontal gyrus (MeFG)/anterior cingulate (ACC) (BA 9/32), and the right cerebellum (Fig. 2; Table II).

Lexical Meaning

Our next step aimed at identifying the subset of regions that are involved in the processing of the lexical meaning of *some*. For that purpose, we conducted a conjunction analysis of all the *some* conditions with the *every*ALL condition (*some*ALL > *every*ALL, *some*SOME > *every*ALL, and *some*NONE > everyALL). However, no brain region showed increased activation in this conjunction. This result seems to suggest that processing differences related to the lexical meaning of the two quantifiers (*some* and *every*) do not drive the activations observed in the baseline conjunction and in the following analyses.

To further test the activations related to the lexical meaning, we compared the *some*NONE and *every*NONE conditions. These two conditions match on both response type and picture type, but differ on the lexical item. In this comparison (*some*NONE > *every*NONE; Table II), we observed activations only in the occipital lobe (left and right BA 17/18). This further confirms that the lexical meaning of *some* does not load on cognitive resources more than the lexical meaning of *every*.

Implicature Generation

Based on the previous analysis, we examined the activations related to the *some* conditions, excluding the *some*NONE, in order to determine which areas are related to the implicature generation. It is unclear whether the *some*NONE condition induces the generation of implicatures because it is possible to make the correct response based on the lexical meaning of *some* (i.e., any quantity greater than none). Thus, we examined both successful implicatures, using the *some*SOME condition, and mismatched implicatures, using the *some*ALL condition. These two conditions share processes of implicature generation, thus an inclusive conjunction of areas shown in their comparison with no implicature conditions should be attributed to this function. A conjunction analysis of the individual comparisons of these conditions with the *every*ALL condition (*some*ALL > *every*ALL and *some*SOME > *every*ALL) revealed activation in the left IFG (BA 47) (Table II). Importantly, this area was also observed in our baseline conjunction analysis (which compared the implicature mismatch condition with the no implicature conditions).

Implicature Mismatch

Next, we looked for activations that can be attributed to the implicature mismatch, beyond the implicature generation. We therefore compared the implicature mismatch

[4]It is unclear what the correct response (true or false) for the implicature mismatch condition is. In fact, under certain interpretations, each response could be correct. Therefore, it is unclear whether the mismatch condition elicits the same response-related activations as the completely-true or completely-false conditions. Importantly, thus, the conjunction analysis compared *some*ALL condition to conditions that included both completely-true (*every*ALL) and completely-false (*every*SOME and *every*NONE) responses.

TABLE II. Areas of activations in the different analyses performed in order to characterize activations associated with scalar implicature generation and scalar implicature mismatch ($P < 0.005$, cluster size of $k > 50$ voxels, and cluster-level FWE correction of $P < 0.05$)

Region	*x*	*y*	*z*	*K*	*t* max
Conjunction of *some*ALL vs. the *every* conditions (implicature generation and implicature mismatch)					
Left anterior MFG (BA 10)	−30	50	10	220	5.34
Left IFG (BA 47)	−48	29	2	111	5.01
Right cerebellum	15	−85	−26	82	4.67
Right MFG (BA 10)	33	56	6	65	4.44
MeFG/ACC (BA 32/9)	−6	23	42	76	4.17
Conjunction of *some*ALL and *some*SOME vs. *every*ALL condition (implicature generation)					
Left IFG (BA 47)	−36	17	−22	56	6.7
Conjunction of *some*ALL vs. the other *some* conditions (implicature mismatch)					
Left anterior MFG (BA 10)	−27	44	−2	137	8.01
MeFG/ACC (BA 32/9)	−6	32	42	92	4.5
Comparison of *some*NONE vs. *every*NONE (lexical meaning)					
Right Occiptal (BA 17/18)	27	−85	−10	161	6
Left Occiptal (BA 17/18)	−15	85	−2	56	5.64

condition, *some*ALL, with the *some*SOME condition that involves implicature generation, but not implicature mismatch. To reduce effects that are related to the response type, we also included the *some*NONE condition in this analysis: The response for the *some*ALL condition can be either true or false, whereas the response to the *some*SOME condition is true and the response to the *some*NONE condition is false. The conjunction analysis of the individual comparisons (*some*ALL > *some*SOME and *some*ALL > someNONE) revealed increased activations for the *some*ALL condition in the left anterior middle frontal gyrus (MFG) (BA 10) and the MeFG/ACC (Table II). These areas have also been observed in our baseline conjunction.

ROI analysis

Using an ROI analysis, we further examined the activation pattern of the *some*SOME and the *some*NONE conditions in the areas identified in the baseline conjunction (which show increased activation with the *some*ALL condition compared to the *every* conditions). This could further point to the roles of the regions in the processing of scalar implicatures. In the left IFG (BA 47), the beta values of the *some*SOME condition were significantly higher compared with the *every* conditions ($F(2,11) = 9.89$, $P = 0.003$), whereas those of the *some*NONE condition were not ($F(2,11) = 1.15$, $P = 0.35$). The same pattern was found in the right MFG ($F(2,11) = 4.5$, $P = 0.03$, and $F(2,11) = 0.13$, $P = 0.87$ for the *some*SOME and the *some*NONE conditions, respectively). In the left MFG, the MeFG/ACC and the cerebellum, both conditions did not show any difference compared to the *every* conditions ($F(2,11) = 2.9$, $P = 0.1$, $F(2,11) = 2.5$, $P = 0.12$, and $F(2,11) = 0.31$, $P = 0.73$ for the *some*SOME condition respectively, and $F(2,11) = 0.96$, $P = 0.41$, $F(2,11) = 0.19$, $P = 0.82$ and $F(2,11) = 1.22$, $P = 0.33$ for the *some*NONE condition respectively). Note that the baseline conditions (the *every* conditions) were used for both the ROI identification and the ROI analysis. A bias resulting from this non-independence should have influenced the *some*SOME and the *some*NONE comparisons in the same way. Thus, our ROI analysis further confirms the difference between the *some*SOME condition and the *some*NONE condition.

DISCUSSION

Sentences that include weak scalar terms, like *some*, involve the generation of scalar implicatures, leading to an interpretation of *some* that differs from its lexical (logical) meaning. On the basis of behavioral studies, researchers have argued that the generation of scalar implicature involves processing costs beyond the processing of simple sentences [e.g., Guasti et al., 2005; Noveck, 2001; Pouscoulus and Noveck, 2009]. We hypothesized that implicature mismatch, which was frequently used in those studies, could also contribute to the processing cost. Implicature mismatch occurs when the context does not match the implicature (e.g., under our world knowledge every giraffe has a long neck, thus the sentence "some giraffes have long necks" is a case of implicature mismatch).

The main goal of our study was to characterize the neural correlates of the processing cost associated with implicature generation and implicature mismatch and to isolate these two processes. This was done using cases of implicature mismatch, cases of successful implicature and cases of no implicature. Several brain areas, the left IFG (BA 47), right and left anterior MFG (BA 10), MeFG/ACC and the right cerebellum, were identified in a conjunction analysis of the single pair comparisons of the implicature mismatch condition with each one of the no implicature conditions. Note that the implicature mismatch condition included implicature generation (which must occur for the implicature to fail), thus this analysis could not distinguish between the two processes.

It is also possible that the lexical meaning of *some* generates a greater load compared to the lexical meaning of *every*. Our baseline conjunction analysis could not determine the effects of the lexical meaning of *some*, because we compared sentences with *some* and sentences with *every*. However, another conjunction of each of the *some* conditions compared to one of the *every* conditions showed no activations. This finding suggests that lexical meanings of the two quantifiers do not require different cognitive resources (this is not to suggest that no processing occurs with the lexical item, but simply that *some* does not require more processing than *every*). Another analysis comparing the *some*NONE and the *every*NONE conditions (that match on both the picture type and the expected response) supported the activation similarities of the lexical meanings of *some* and *every*. In this comparison, we observed increased activations for the *some* condition only in occipital areas. These areas are included in the visuospatial processing network [e.g., Vannini et al., 2004]. It is unlikely that these activations are related to lexical-semantic processing of quantifiers. These visual-related activations can be explained by the need to perform a more elaborate visual inspection for the *some*NONE condition to make a correct response[5]. For the *every*NONE condition, it is sufficient to detect one character that does not have the property mentioned in the sentence to make a response, whereas for the *some*NONE condition, one has to verify that more than one character has that property.

The subsequent steps in our analysis examined whether the processing cost observed with the mismatch condition can be attributed to implicature generation only, implicature mismatch only, or both. In this connection, we assessed the brain activation pattern of mismatched and successful implicatures: (1) we examined activations shared by both conditions using a conjunction analysis in order to identify areas specifically related to implicature generation and (2) we examined which areas show increased activations for implicature mismatch compared with successful implicatures in order to identify areas related to implicature mismatch only. Our results indicate that the processing cost is induced by both implicature generation and implicature mismatch, each showing a different brain activational pattern: The implicature generation can be linked to the left IFG (BA 47) and the implicature mismatch can be linked to the left anterior MFG (BA 10) and the MeFG/ACC.

Implicature Generation: Left IFG (BA 47)

Our whole brain analysis, as well as the ROI results, suggests that the left IFG (BA 47) is involved in generating scalar implicatures. BA 47 was observed in an inclusive conjunction analysis of the mismatched and successful implicature conditions (vs. a no implicature condition). This analysis was aimed at showing only the areas that were activated in both of the conditions (to put it in other words, processes related to implicature mismatch which were present only in one of the two conditions would not be detectable through this analysis). Furthermore, BA 47 was ***not*** observed in the conjunction of the implicature mismatch condition (*some*ALL) with the other *some* conditions (*some*SOME & *some*NONE), which was designed to excluded activations related to implicature generation (because these were factored out in the comparison between *some*ALL and *some*SOME). Additionally, in an ROI analysis, the activation in BA 47 was found to be significantly higher for the *some*SOME condition, which includes implicature generation, compared with the *every* conditions, which do not include implicatures (see the Results section for a discussion of the non-independence bias problem).

BA 47 is the subregion of the left IFG that has been canonically linked to semantic processing [see meta-analysis studies, e.g., Binder et al., 2010; Bookheimer, 2002; Fiez, 1997] and has been identified as one of the key regions for semantic processing in a recent meta-analysis [Binder et al., 2010]. Activations in this region have been observed in studies examining sentence-level semantics [Dapretto and Bookhiemer, 1999; Homae et al., 2002]. It has been argued that this section of the left IFG is linked to lexical-semantic aspects of sentence processing and to the integration of semantic information at the sentence level [Daperatto and Bookheimer, 1999; Hagoort, 2005; Hagoort et al., 2009; Sakai, 2005]. The role of BA 47 in implicature generation may thus be related to the parallel computation of the meaning of *some* sentences together with their strong scalar *every*-variant, where the negation of the latter results in the enriched meaning of the sentence, i.e., the implicature.

Importantly, BA 47 is not typically implicated in studies of pragmatic processing, which is linked to the right hemisphere in both lesion and neuroimaging studies [e.g., Eviatar and Just, 2006; Giora et al., 2000; Hesling et al., 2004; Kuperberg et al., 2000; Shamay-Tsoory et al., 2005])[6]. Thus, the activation of BA 47 suggests a semantic involvement in the generation of scalar implicature. This fact has implications for the debate regarding the linguistic component that is responsible for generating scalar implicatures. Any account of scalar implicatures assumes that their generation involves two operations: the identification of the alternative set for the sentence S (call it ALT(S)), and the enrichment of the sentence S by means of the alternative set (formalized as ENRICH(S,

[5]This difference between the *some*NONE and *every*NONE conditions indicates that the quantifiers are being processed even in the context where the predicate is not present. If the judgment had been made based on the predicate presence alone, we would not expect any differences between these two conditions in searching the picture.

[6]Though, interestingly, conventional metaphors elicit left hemisphere activations (Eviatar and Just, 2006; Giora et al., 2000; Lee and Dapretto, 2006). Nonetheless, it is assumed that conventional metaphors are lexicalized, and thus, their processing involves the same component as other lexical items (Giora, 2003). That is, they do not involve the pragmatic component.

ALT(S))). The difference between the accounts lies in their assumptions regarding the linguistic component that is responsible for these operations. The traditional view assumes that implicatures are computed at the pragmatic level, after semantic processes have been completed [e.g., Grice, 1975]. Advocates for this approach argue that the delayed look shift in eye-movement paradigm [Huang and Snedeker, 2009a] and the long reading [Breheny et al., 2006] and reaction times (Bott and Noveck, 2004) for sentences with weak scalar expressions suggest that the implicatures are context-depended and occur in a late processing stage. Other views argue, mainly based on the linguistic behavior of scalar implicatures at the embedded level, that these implicatures are generated by a grammatical-semantic component (for detailed account, see for example Chierchia, 2004 and Chierchia et al., 2008). Our results indicate that at least part of processing is semantic. It is possible that both alternative identification and meaning enrichment occur in the same region, and performed by the same (semantic) component. Alternatively, the activation in BA 47 may be related only to the identification of the alternative set ALT(S), whereas the meaning enrichment ENRICH(S, ALT(S)) may occur elsewhere (possibly in a pragmatic component). However, given that BA 47 is the *only* region identified in the conjunction between mismatched and successful implicatures, the results seem to be most directly consistent with the idea that both ALT(S) and ENRICH(S, ALT(S)) are computed by the same component, as the grammatical-semantic approach would have it [e.g., Chierchia, 2004; Chierchia et al., 2008].

Another region that may have a role in generating implicatures is the right MFG (BA 10). Although this region was not observed in our whole-brain analysis of implicature generation, it was more activated for the successful implicature condition (*some*SOME) than for the no implicature conditions in the ROI analysis. The role of this area in language processing is not well-defined. However, activations in the right MFG have been observed with semantic processing (compared with phonological processing, Poldrack et al., 1999).

The *some*NONE condition showed different activational pattern than the *some*SOME and *some*ALL conditions. This was observed in both the whole brain analysis (with the conjunction of the *some* conditions with the *every* condition) and in the ROI analysis. Furthermore, when comparing it to the *every*NONE condition, only activations within visual areas were identified. This may suggest that no implicature is generated with the *some*NONE condition.

Implicature Mismatch: Left Anterior MFG and Medial Frontal Cortex

Implicature mismatch seems to involve two areas: the left anterior MFG (BA 10) and the MeFG/ACC. Both areas were observed in the conjunction of the mismatched implicature condition (*some*ALL) vs. the other *some* conditions (*some*SOME and *some*NONE). This conjunction was aimed to exclude processes of implicature generation and show only activations related to implicature mismatch. Thus, our study confirms that implicature mismatch induces a processing cost, in addition to the implicature generation. Furthermore, this conjunction analysis compared the implicature mismatch with a match (completely-true) and a no-match (completely-false) conditions. The increased activations observed in the analysis suggest that implicature mismatch is more cognitively demanding than the completely-true and completely-false conditions. A different activational pattern for such conditions was also shown in ERP studies [Drenhaus et al., 2006; Noveck and Posada, 2003].

It has been argued that children fail to present adult-like behavior with scalar implicatures, because they do not generate the implicatures [e.g., Huang and Snedeker, 2009b; Noveck, 2001]. This was suggested based on behavioral studies that used mainly cases of implicature mismatch. Our results offer another explanation. It is possible that children, like adults, generate scalar implicatures (as is also suggested by some behavioral studies that used various manipulations to improve children performance with these implicatures, e.g., Guasti et al., 2005; Papafragou and Musolino, 2003; Papafragou and Tantalou, 2004; Verbuk, 2006). However, when the context in which a sentence is presented does not match the implicature, they fail to respond like adults because of the processing cost related to this mismatch. This should be carefully examined when investigating scalar implicatures in children so that the effects of implicature mismatch on their behavior can be factored in.

We have suggested that implicature mismatch is costly due to the conflicts between the two interpretations of *some*, or the difficulty to determine the truth value of a sentence in a mismatch condition. Further research is needed in order to determine what guides the processing cost related to implicature mismatch, as our study was not designed to provide an answer to this question. However, some suggestions can be made on the basis of the functions previously attributed to the areas that we have identified.

The prefrontal cortex, including the anterior MFG and the MeFG/ACC, have been consistently linked to a variety of high cognitive functions such as working memory, attention, reasoning and cognitive control [e.g., Bush et al., 2000; Cabeza, and Nyberg. 2000; Carter et al., 1998; Gallagher and Frith, 2003; MacDonald et al., 2000; Monti et al., 2007; Ridderinkhof et al., 2004; Rugg et al., 2003]. Interestingly, activations in the left MFG were observed for mismatch cases of learnt rules [Bunge et al., 2003; Wolfensteller and von Cramon, 2010, 2011]. Furthermore, there is some evidence that this region is related to evaluation in yes/no judgment tasks [Wendelken et al., 2008, though see their argumentation that this area is associated with a specific type of evaluation and integration]. Others have linked the left anterior MFG to the integration of several sources of higher-order information [e.g., Bunge et al., 2005; Christoff et al., 2001; Wendelken et al., 2011] or self-generated information [Christoff et al., 2003]. However, Wolfensteller and von Cramon [2011] suggested that activation in this area might reflect the mismatch result of the integration process or may be associated with strategy processes, rather than reflect the integration process itself.

The role of the left MFG in evaluating the truth value of the sentences, as well as in integrating self-generated high-order information, may account for the increased processing demands that occur during implicature mismatch. It is possible that the processing cost, which is linked to implicature mismatch, results from difficulties to determine the truth value of a sentence with a weak scalar expression in the specific mismatch context. When *some* sentences are presented in the context where the total set holds, like in our implicature mismatch condition, making a call on the truth value of the sentence is clearly quite hard. Under the logical meaning of *some*, the sentence is true, but under the enriched meaning (derived by the implicature) the sentence is false. Such ambiguity is likely to induce a processing load in areas involved in truth value judgment. Specifically, the activation in this area was observed when comparing the implicature mismatch with completely true and completely false conditions (for which it was easier to determine the truth value of the sentences).

The MeFG/ACC was also implicated with regard to implicature mismatch in this study. Like the left MFG, the MeFG/ACC has been linked to high cognitive functions. Of a special interest is the role of this area in conflict monitoring [e.g., Bartholow et al., 2005; Carter, and van Veen, 2007; Mansouri et al., 2009]. Based on several neuroimaging studies that have observed activations in this area in different tasks in which information processing results in a conflict between alternatives [e.g., Barch et al., 2000; Egner, and Hirsch, 2005; Kuhl et al., 2007; Maril et al., 2001; van Veen et al., 2001], it has been suggested that the ACC detects conflicts or conditions in which conflict may occur [e.g., Carter et al., 1998; Carter, and van Veen, 2007; Mansouri et al., 2009]. In the mismatch condition in our study, a conflict arises between the logical meaning and the enriched meaning in a certain context. Thus, the activation in the left MeFG/ACC may be the result of this conflict.

Alternatively, the activation in this area may be related to its role in tasks that require Theory of Mind (ToM) [Amodio and Frith, 2006; Gallagher and Frith, 2003; Walter et al., 2004]. According to the classic linguistic approach to scalar implicatures, ToM is assumed to be involved in the generation of implicatures, as the listener speculates about the intentions of the speaker [Flobbe et al., 2008; Grice, 1975; Pijnacker et al., 2009]. The results of our study, however, did not show the canonical ToM network activation [as shown, for example in Amodio and Frith, 2006; Brune, and Brune-Cohrs, 2006; Saxe and Kanwisher, 2003] with scalar implicature generation. It is possible that ToM is recruited in order to solve the ambiguity presented in the case of implicature mismatch. As the logical and the enriched meaning collide, the listener has to draw some inferences about the speaker's knowledge and her cooperative intensions. This may lead to a greater activation in brain regions that are related to ToM but only in the condition of implicature mismatch.

The right cerebellum was also observed in the baseline conjunction of the implicature mismatch condition compared with the no implicature conditions. However, no activation was found in this area in the other analyses that we performed. Thus, our study cannot determine the role of this area in the processing of scalar implicatures. Nonetheless, the right cerebellum was previously linked to language processing [see for example a meta-analysis of neuroimaging studies, Stoodley and Schmahmann, 2009], and specifically to semantic processing [e.g., McDermott et al., 2003; Noppeney and Price, 2002; Roskies et al., 2001; Xiang et al., 2003].

CONCLUSIONS

This is the first fMRI study to examine the processing of scalar implicatures. The results of this study join the established body of research from different methodologies showing the psycholinguistic reality of scalar implicatures. Our results suggest that a subregion of the left IFG (BA 47) is involved in the generation of scalar implicatures. This region has been consistently linked to semantic processing, and not to pragmatic processing. This finding appears to be most directly consistent with grammatically oriented approaches to implicatures [e.g. Chierchia et al. 2008], though other hypotheses cannot be altogether ruled out. We further observed a processing cost with implicature mismatch beyond and in addition to the processing of generating the implicature. This was observed in the left anterior MFG and the MeFG/ACC, which are associated with high-order cognitive functions. Importantly, the implicature mismatch elicited brain patterns that differed from that of completely true or completely false sentences. Our findings should be considered in future research of scalar implicatures, as the source of processing cost (expressed in delayed reaction times, look shifts, differential brain activations etc.) observed in cases when the implicature and the context do not match compared with cases without any implicatures may be explained in the difficulty to make a response rather than in the difficulty to generate the implicatures.

REFERENCES

Amodio DM, Frith CD (2006): Meeting of minds: The medial frontal cortex and social cognition. Nat Rev Neurosci 7:268–277.

Barch DM, Braver TS, Sabb FW, Noll DC (2000): Anterior cingulate and the monitoring of response conflict: Evidence from an fMRI study of overt verb generation. J Cogn Neurosci 12:298–309.

Bartholow BD, Pearson MA, Dickter CL, Sher KJ, Fabiani M, Gratton G (2005): Strategic control and medial frontal negativity: Beyond errors and response conflict. Psychophysiology 42:33–42.

Binder JR, Desai RH, Graves WW, Conant LL (2009): Where is the semantic system? A critical review and meta-analysis of 120 functional neuroimaging studies. Cerebral Cortex 19:2767–2796.

Bookheimer SY (2002): Functional MRI of language: New approaches to understanding the cortical organization of semantic processing. Annual Rev Neurosci 25:151–188.

Bott L, Noveck IA (2004): Some utterances are underinformative: The onset and time course of scalar inferences. J Memory Lang 51:437–457.

Breheny R, Katsos N, Williams J (2006): Are generalised scalar implicatures generated by default? An on-line investigation into the role of context in generating pragmatic inferences. Cogn 100:434–463.

Brune M, Brune-Cohrs U (2006): Theory of mind: Evolution, ontogeny, brain mechanisms and psychopathology. Neurosci Biobehav Rev 30:437–455.

Bunge SA, Kahn I, Wallis JD, Miller EK, Wagner AD (2003): Neural circuits subserving the retrieval and maintenance of abstract rules. J Neurophysiol 90:3419–3428.

Bunge SA, Wendelken C, Badre D, Wagner AD (2005): Analogical reasoning and prefrontal cortex: Evidence for separable retrieval and integration mechanisms. Cerebral Cortex 15:239–249.

Bush G, Luu P, Posner MI (2000): Cognitive and emotional influences in anterior cingulate cortex. Trends Cogn Sci 4:215–222.

Cabeza R, Nyberg L (2000): Imaging cognition. II. An empirical review of 275 PET and fMRI studies. J Cogn Neurosci 12:1–47.

Carter CS, van Veen V (2007): Anterior cingulate cortex and conflict detection: An update of theory and data. Cogn Affective Behav Neurosci 7:367–379.

Carter CS, Braver TS, Barch DM, Botvinick MM, Noll DC, Cohen JD (1998): Anterior cingulate cortex, error detection, and the online monitoring of performance. Science 280:747–749.

Chierchia G (2004): Scalar implicatures, polarity phenomena, and the syntax/pragmatics interface. In: Belletti A, editor. Structures and Beyond. Oxford: Oxford University Press.

Chierchia G, Fox D, Spector B (2008): The grammatical view of scalar implicatures and the relationship between semantics and pragmatics. In: Portner P, Maienborn C, von Heusinger K, editors. Handbook of Semantics. New York, NY: Mouton de Gruyter.

Christoff K, Prabhakaran V, Dorfman J, Zhao Z, Kroger JK, Holyoak KJ, Gabrieli JD (2001): Rostrolateral prefrontal cortex involvement in relational integration during reasoning. Neuroimage 14:1136–1149.

Christoff K, Ream JM, Geddes LPT, Gabrieli, JDE (2003): Evaluating self-generated information: Anterior prefrontal contributions to human cognition. Behav Neurosci 117:1161–1168.

Dale PS, Fenson L (1996): Lexical development norms for young children. Behav Res Methods Instr Comput 28:125–127.

Dapretto M, Bookheimer SY (1999): Form and content: Dissociating syntax and semantics in sentence comprehension. Neuron 24:427–432.

Drenhaus H, Beim Graben P, Frisch S (2006): Not all but some ERP results on the scalar expressions some and all. A poster presented at the annual meeting of the Cognitive Neurosciennece Society, 2006, San Francisco, CA.

Egner T, Hirsch J (2005): Cognitive control mechanisms resolve conflict through cortical amplification of task-relevant information. Nat Neurosci 8:1784–1790.

Eviatar Z, Just MA (2006): Brain correlates of discourse processing: An fMRI investigation of irony and conventional metaphor comprehension. Neuropsychologia 44:2348–2359.

Feeney A, Scrafton S, Duckworth A, Handley SJ (2004): The story of some: Everyday pragmatic inferences by children and adults. Can J Exp Psychol 58:121–132.

Fiez JA (1997): Phonology, semantics and the role of the left inferior prefrontal cortex. Hum Brain Mapp 5:79–83.

Flobbe L, Verbrugge R, Hendriks P, Krämer I (2008): Children's application of theory of mind in reasoning and language. J Logic Lang Inform 17:417–442.

Friston KJ, Holmes AP, Worsley KJ, Poline JB, Frith CD, Frackowiak RSJ (1995): Statistical parametric maps in functional imaging: A general linear approach. Hum Brain Mapp 2:189–210.

Gallagher HL, Frith CD (2003): Functional imaging of "theory of mind". Trends Cogn Sci 7:77–83.

Gadzar G (1979): Pragmatics: Implicature, Presupposition and Logical Form. New York: Academic Press.

Giora R (2003): On Our Mind: Salience, Context and Figurative Language. New York: Oxford University Press.

Giora R, Zaidel E, Soroker N, Batori G, Kasher A (2000): Differential effects of right- and left-hemisphere damage on understanding sarcasm and metaphor. Metaphor Symbol 15:63–83.

Guasti MT, Chierchia G, Crain S, Foppolo F, Gualmini A, Meroni L (2005): Why children and adults sometimes (but not always) compute implicatures. Lang Cogn Proc 20:667–696.

Grice HP (1975): Logic and conversation. In: Cole P, Morgan JL, editors. Syntax and Semantics Vol. 3. New York: Academic Press. pp 41–58.

Hagoort P (2005): On Broca, brain, and binding: A new framework. Trends Cogn Sci 9:416–423.

Hagoort P, Baggio G, Willems RM (2009): Semantic unification. In: Gazzaniga M, editor. The Cognitive Neurosciences. Cambridge, MA: MIT Press. pp 819–836.

Hendriks P, Hoeks J, de Hoop H, Krämer I, Smits EJ, Spenader J, de Swart H (2009): A large-scale investigation of scalar implicature. In: Sauerland U, Atsushiro K, editors. Semantics and pragmatics: From experiment to theory. Hampshire, UK: Palgrave Studies in Pragmatics, Language and Cognition, Palgrave Macmillan, Houndmills, Basingstoke. pp 30–50.

Hesling I, Clement S, Bordessoules M, Allard M (2005): Cerebral mechanisms of prosodic integration: Evidence from connected speech. Neuroimage 24:937–947.

Homae F, Hashimoto R, Nakajima K, Miyashita Y, Sakai KL (2002): From perception to sentence comprehension: The convergence of auditory and visual information of language in the left inferior frontal cortex. NeuroImage 16:883–900.

Horn L (1972): On the semantic properties of the logical operators in English. Doctoral Dissertation, UCLA, Los Angeles, CA.

Horn L (1989): A Natural History of Negation. Chicago, IL: University of Chicago Press.

Huang Y. Snedeker J (2009a): On-line interpretation of scalar quantifiers: Insight into the semantics-pragmatics interface. Cognitive Psychol 58:376–415.

Huang Y. Snedeker J (2009b): Semantic meaning and pragmatic interpretation in five-year olds: Evidence from real time spoken language comprehension. Dev Psychol 45:1723–1739.

Kuhl BA, Dudukovic NM, Kahn I, Wagner AD (2007): Decreased demands on cognitive control reveal the neural processing benefits of forgetting. Nat Neurosci 10:908–914.

Kuperberg GR, McGuire PK, Bullmore ET, Brammer MJ, Rabe-Hesketh S, Write IC, Lythogoe DJ, Williams SCR, David AS (2000): Common and distinct neural substrates for pragmatic, semantic, and syntactic processing of spoken sentences: An fMR study. J Cogn Neurosci 12:321–341.

Lee SS, Dapretto M (2006): Metaphorical vs. literal word meanings: fMRI evidence against a selective role of the right hemisphere. NeuroImage 29:536–544.

Levinson S (2000): Presumptive Meanings. Cambridge, MA: MIT Press.
Mansouri FA, Tanaka K, Buckley MJ (2009): Conflict-induced behavioural adjustment: A clue to the executive functions of the prefrontal cortex. Nat Rev Neurosci 10:141–152.
McDermott KB, Petersen SE, Watson JM, Ojemann JG (2003): A procedure for identifying regions preferentially activated by attention to semantic and phonological relations using functional magnetic resonance imaging. Neuropsychologia 41:293–303.
MacDonald AW, Cohen JD, Stenger VA, Carter CS (2000): Dissociating the role of the dorsolateral prefrontal and anterior cingulate cortex in cognitive control. Science 288:1835–1838.
Maril A, Wagner AD, Schacter DL (2001): On the tip of the tongue: An event-related fMRI study of semantic retrieval failure and cognitive conflict. Neuron 31:653–660.
Monti MM, Osherson DN, Martinez MJ, Parsons LM (2007): Functional neuroanatomy of deductive inference: A language-independent distributed network. Neuroimage 37:1005–1016.
Noppeney U, Price CJ (2002): A PET study of stimulus- and task-induced semantic processing. NeuroImage 15:927–935.
Noveck IA (2001): When children are more logical than adults: Experimental investigations of scalar implicatures. Cognition 78:165–188.
Noveck I, Posada A (2003): Characterising the time course of an implicature. Brain Lang 85:203–210.
Noveck IA, Sperber D (2007): The why and how of experimental pragmatics: The case of 'scalar inferences'. In: Burton-Roberts, editor. Advances in Pragmatics. Basingstoke: Palgrave.
Papafragou A, Musolino J (2003): Scalar implicatures: Experiments at the semantics-pragmatics interface. Cognition 86:253–282.
Papafragou A, Tantalou N (2004): Children's computation of implicatures. Lang Acquisition 12:71–82.
Pijnacker J, Hagoort P, Buitelaar J, Teunisse J, Geurts B (2009): Pragmatic inferences in high-functioning adults with autism and Asperger syndrome. J Autism Dev Disorders 39:607–618.
Poldrack RA, Wagner AD, Prull MW, Desmond JE, Glover GH, Gabrieli JDE (1999): Functional specialization for semantic and phonological processing in the left inferior prefrontal cortex. NeuroImage 10:15–35.
Pouscoulous N, Noveck IA, Politzer G, Bastide A (2007): A developmental investigation of processing costs in implicature production. Language Acquisition 14:347–375.
Pouscoulous N, Noveck IA (2009): Developmental aspects of the semantic/pragmatic distinction. In Foster-Cohen S, editor. Advances in Language Acquisition. London: Palgrave Macmillan (in press).
Price CJ, Friston KJ (1997): Cognitive conjunction: A new approach to brain activation experiments. NeuroImage 5:261–270.
Ridderinkhof KR, Ullsperger M, Crone EA, Nieuwenhuis S (2004): The role of the medial frontal cortex in cognitive control. Science 306:443–447.
Roskies AL, Fiez JA, Balota DA, Raichle ME, Petersen SE (2001): Task-dependent modulation of regions in the left inferior frontal cortex during semantic processing. J Cogn Neurosci 13:829–843.
Rugg MD, Henson RN, Robb WG (2003): Neural correlates of retrieval processing in the prefrontal cortex during recognition and exclusion tasks. Neuropsychologia 41:40–52.
Sakai KL (2005): Language acquisition and brain development. Science 310:815–819.
Saxe R, Kanwisher N (2003): People thinking about thinking people. The role of the temporo-parietal junction in ''theory of mind''. NeuroImage 19:1835–1842.
Shamay-Tsoorym SG, Tomer R, Aharon-Peretz J (2005): The neuroanatomical basis of understanding sarcasm and its relationship to social cognition. Neuropsychology 19:288–300.
Smith C (1980): Quantifiers and question-answering in young children. J Exp Child Psychol 30:191–205.
Stoodley CJ, Schmahmann JD (2009): Functional topography in the human cerebellum: A meta-analysis of neuroimaging studies. NeuroImage 44:489–501.
van Veen V, Cohen JD, Botvinick MM, Stenger VA, Carter CS (2001): Anterior cingulate cortex, conflict monitoring, and levels of processing. Neuroimage 14:1302–1308.
Vannini P, Almkvist O, Franck A, Jonsson T, Volpe U, Kristoffersen WM, Wahlund LO, Dierks T (2004): Task demand modulations of visuospatial processing measured with functional magnetic resonance imaging. NeuroImage 21:58–68.
Verbuk A (2006): Acquisition of scalar implicatures: When some of the crayons will do the job. Proceedings of the 31st Boston University Conference on Language Development.
Walter H, Adenzato M, Ciaramidaro A, Enrici I, Pia L, Bara BG (2004): Understanding intentions in social interaction: The role of the anterior paracingulate cortex. J Cogn Neurosci 16:1854–1863.
Wendelken C, Nakhabenko D, Donohue SE, Carter CS, Bunge SA (2008): Brain is to thought as stomach is to ??: Investigating the role of rostrolateral prefrontal cortex in relational reasoning. J Cogn Neurosci 20:682–693.
Wendelken C, Chung D, Bunge SA (2011): Rostrolateral prefrontal cortex: Domain-general or domain-sensitive? Hum Brain Mapp 33:1952–1963.
Wolfensteller U, von Cramon DY (2010): Bending the rules: Strategic behavioral differences are reflected in the brain. J Cogn Neurosci 22:278–291.
Wolfensteller U, von Cramon DY (2011): Strategy-effects in prefrontal cortex during learning of higher-order S–R rules. NeuroImage 57:598–607.
Xiang H, Lin C, Ma X, Zhang Z, Bower JM, Weng X, Gao JH (2003): Involvement of the cerebellum in semantic discrimination: An fMRI study. Hum Brain Mapp 18:208–214.